

## Performance Analysis of HOM in LTE Small Cell

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**Abstract:** This paper deals with the performance analysis of HOM (higher order modulation) in LTE-A system. Firstly, we analyzed the requirement of HOM in small cell deployment, and then we analyzed the problem of EVM (Error Vector Magnitude) modeling in LTE system. With the assumption of small cell deployment, some link level simulation results are proposed, where the impacts of EVM on different MCS (modulation coding style) are compared. The simulation results show that the performance of HOM in small cell is very sensitive to EVM. In this paper, the other factors which would impact the performance of HOM are also mentioned. Copyright © 2014 IFSA Publishing, S. L.

**Keywords:** LTE-A, EVM, HOM, Small cell.

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### 1. Introduction

In LTE-A, the enhancements for improved spectral efficiency is one of the main study areas. Currently, with the introduction of small cell deployment in LTE-A, studying potential enhancements to improve the spectrum efficiency has become a hot topic [1].

The introduction of high order modulation can be a straight forward way increase the special efficiency. In previously research, it is known that the performance gain for higher order modulation will need higher SINR or smaller EVM [2-4]. In a typical scenario for small cell, unless the density is too high, high SINR ranges can be expected, especially for isolated indoor cases. Hence, there could a large percent of UEs which could satisfy the geometry requirement for 256 QAM, e.g. >20 dB. Further, a small cell normally operates with lower TX power due to the small coverage, which also makes it more feasible to implement certain high order modulation.

Supporting 256-QAM will increase the peak data rate of a UE in theory by 33 % since modulation

order increases from 6 to 8. Ideally, by increasing the highest modulation from 64 QAM to 256 QAM, up to 33 % gain on the peak data rate can be achieved [5, 6].

Although HOM can provide great performance gain over lower order modulation, there still have some constraint factor in practical small cell deployment. For example, systems which employ higher order modulation schemes are potentially more sensitive to multipath propagation effects, inter-cell interference and thermal noise as well as the degradations imposed by practical manufacturing constraints.

As discussed in early 3GPP meetings, EVM (Error Vector Magnitude) can be an important factor which impacts the benefit of HOM (e.g. 256 QAM). Hence, the link throughput with ideal EVM and realistic 4 % EVM should be considered in the introduction of HOM.

Compared with existing modulation schemes specified in 3GPP TS 36.211 (Release 11), 256-QAM modulation requires higher SINR at the receiver to achieve the same error performance. For example, to

achieve a similar BER performance as 64 QAM, 256 QAM theoretically requires around a 6 dB higher SNR. Evaluations should take into account both inter cell interference and hardware related impairments that can impact the achievable SINR in different deployment scenarios.

There are many aspects that interact when determining the overall benefit of 256 QAM, and EVM is one of the most important facts which will have great impact on HOM performance. Then, in this paper, we mainly studied the EVM modeling and analyzed the impact of EVM on HOM performance. The contributions of this paper are as follows.

1) We Studied the EVM principle and EVM modeling in LTE-A system.

2) We analyzed the performance impact of EVM on HOM in small cell.

The paper is organized as follows. We outline the small cell system modeling in LTE-A system in section 2. In section 3, we introduce the EVM model in transmitter. The simulation assumption and results, as well as the discussion are given in section 4. Finally we conclude this paper in section 5.

## 2. Small Cell Deployment in LTE-A

The deployment of small cell can be illustrated in Fig. 1, where the scheduled UE can be connected to both small cell eNB and macro cell eNB. From the deployment of small cell which can be shown in Fig. 1, it is noticed that in a typical scenario for small cell, unless the density is too high, high SINR ranges can be expected, especially for isolated indoor cases. As discussed in the previous part, the introduction of HOM (high order modulation) can be a straightforward way increase the special efficiency. Hence, with the deployment of small cell, there could a large percent of UEs which could satisfy the geometry requirement for HOM, e.g. 256 QAM modulations.

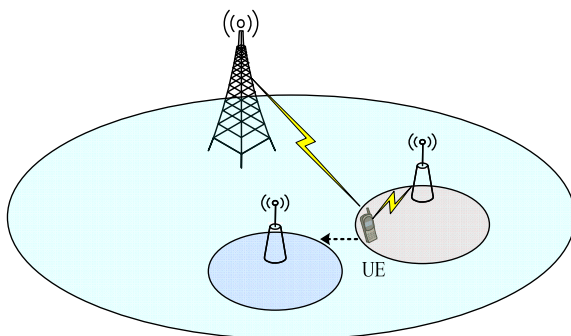


Fig. 1. Illustration of small cell deployment.

Further, a small cell normally operates with lower TX power due to the small coverage, which also makes it more feasible to implement certain high order modulation.

## 3. Measurement and Modeling

As mentioned above, ideally, by increasing the highest modulation from 64 QAM to 256 QAM, up to 33 % gain on the peak data rate can be achieved. While we also noticed that EVM is an important factor which will has great impact on the benefit of HOM. Hence, in this part, we will analysis the EVM affection.

### 3.1. EVM Measurement

Most digital communication standards rely upon In-Phase (I) and Quadrature (Q) modulation to encode digital data onto the RF signal. I/Q modulation coding schemes include quadrature amplitude modulation (QAM) and phase shift keying (PSK). Fig.1 shows constellation diagrams for various coding schemes. The density of the constellation defines the number of bits per constellation symbol. For example, each 64-QAM constellation symbol represents 6 bits of digital data.

EVM measurement can provide a great deal of sight into LTE modulation performance. EVM is expressed as the difference between the vector of an ideal symbol and the symbol under test. It is the percentage of error that indicates how fare the symbol is transmitted from its ideal position. It is noticed that the higher the modulation, the higher the number of symbols, which results in a smaller margin of error.

The EVM is defined as the RMS value of the error vector difference between the ideal reference signal and the measured signal. Its generic form can be written as follows:

$$EVM_{RMS} = \sqrt{\frac{\text{Ave}\left(\sum |S_i - r_i|^2\right)}{\text{Ave}\left(\sum |r_i|^2\right)}} \quad (1)$$

where Ave( $\bullet$ ) is the average calculation and are the ideal reference signal and the measured signal, respectively.

### 3.2. EVM Modeling in LTE-A

Generally, the EVM effect is modeled as AWGN in the transmitter side in the simulation. Some issues about the modelling of EVM and receiver impairments are clarified in this section. For Tx EVM, the noise variance of the modeled EVM will be defined relative to the power on each antenna according to:

$$\sigma_{iotx1}^2 = I_{or1} \cdot evm^2, \quad (2)$$

where  $\sigma_{iotx1}^2$  is the AWGN noise variance which is added at the transmitter, and  $I_{or1}$  is the total transmit power spectral density (integrated in a bandwidth corresponding to the transmission bandwidth configuration) of the downlink signal, as measured at the eNodeB antenna connector.

In LTE system, considered that the reference point for Tx EVM measurement, the Tx EVM is simply modeled by adding a Gaussian noise before

IFFT at transmitter, which can be shown in Fig. 2. That is, the EVM noise is added per Tx antenna with the average power proportional to the Tx power per Tx antenna.

Note that actually we also observed that it doesn't matter whether the TX EVM noise is put before or after IFFT transforming.

It is noticed that RX impairments is also a factor which can degrade system performance, while this is out of the range of this paper.

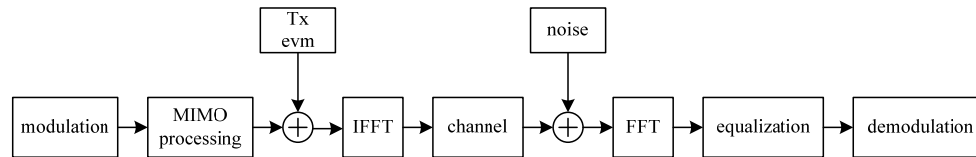


Fig. 2. Illustration of Tx EVM modeling on transmitter side.

#### 4. The Impact of EVM on HOM

For QAM signals, the higher the order of the constellation is, the smaller the minimum phase shift to cause decision errors [3]. Thus higher order modulation is more sensitive to realistic implementation issues, such as the noise figure of the receiver, waveform distortion in the transmitter, and the effects of pulse shaping filters and LP/BP filters. Compared to lower order modulation schemes, the sensitivity of higher order modulation to implementation losses imposes more stringent requirements on the linearity of all the semiconductor components from baseband to RF front end at the transceivers, especially for the power amplifiers. The error vector magnitude (EVM) is used to specify the maximum allowable imperfections in the transmitted signal. Selection of the maximum allowable EVM value always involves a trade-off between the performance loss arising from the imperfections and the additional costs imposed on the transmitter to constrain the imperfections. A higher EVM value is therefore typically specified for lower order modulation schemes which are less sensitive to imperfections.

Although with 256 QAM, the maximum peak rate increase is 33 compared to 64 QAM used in current systems, higher modulation scheme puts on substantial peak computational complexity at both the transmitter and receiver. Therefore, the benefits should be demonstrated on both system level and link level in practical deployments with realistic EVM assumptions on a small cell Tx implementation and on the UE Rx implementation. Herein we provide some preliminary performance evaluations of 256 QAM taking factors such as Rx and Tx EVM, into account. Moreover, we give SINR CDFs for the ITU Indoor Hotspot scenarios for a range of resource utilizations, to assess the probability of the SINR ranges required to achieve gains with 256 QAM.

For 256 QAM, much lower EVM values are typically needed because of the increased sensitivity.

Careful consideration will need to be given to what level of additional costs thereby imposed on the transmitter may be considered to be acceptable, especially considering that 256 QAM would be proposed to be used in pico-eNBs which are typically relatively low cost. In the light of such consideration, a realistic EVM level should be selected for the evaluations. For the receiver, higher order modulation imposes more stringent requirements on the symbol timing recovery, carrier-recovery and equalization. On the one hand, the higher order modulation requires a very small phase jitter to be compatible with steady state or tracking performance of the loop. On the other hand, it requires a wide frequency acquisition range to be compatible with the maximum frequency offset generated between the transmitter and the receiver. To address this issue, a more complex carrier-recovery algorithm is necessary. Therefore, the high peak data rate of higher order modulation would come at the price of significantly more complex and costly implementation.

#### 5. Link Level Simulation

To evaluate the impact of EVM of 256 QAM, the EVM model should be considered. In the evaluation, the EVM effect is modeled as AWGN in the transmitter side in the simulation. As in [3], the noise variance of the modeled EVM will be defined relative to the power on each antenna according to equation (2).

In this part, we provide link level results. The simulation assumptions are provided in following tables, which is based on the agreements in [2].

##### 5.1. Simulation Assumption

The simulation assumption can be as found in Table 1, and the CQI parameter can which is

employed in the link level simulation can be found in Table 2.

**Table 1.** Simulation parameter.

Simulation Parameter	Assumption
MIMO configuration	2x2 with low correlation
EVM	(0,4,6) %
Channel model and Doppler frequency	EPA5
Transmission mode	TM3 (OLSM)
Bandwidth	1.4 MHz
Carrier frequency	3.5 GHz
HARQ	On
UE receiver	MMSE-IRC
Received timing delay (us)	0
Frequency offset	0
UE speed	3 km/h
Metric	Spectrum efficiency [bps/Hz] BLER

**Table 2.** CQI table.

CQI index	Modulation	Code ratex1024	Efficiency
1	QPSK	308	0.6016
2	QPSK	449	0.8770
3	QPSK	602	1.1758
4	16 QAM	378	1.4766
5	16 QAM	490	1.9141
6	16 QAM	616	2.4063
7	64 QAM	466	2.7305
8	64 QAM	567	3.3223
9	64 QAM	666	3.9023
10	64 QAM	772	4.5234
11	64 QAM	873	5.1152
12	64 QAM	948	5.5547
13	256 QAM	803	6.2734
14	256 QAM	889	6.9453
15	256 QAM	952	7.4375

## 5.2. Simulation Result and Discussion

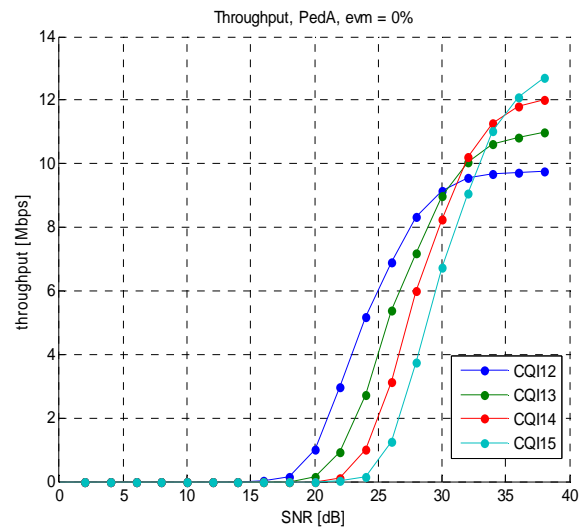
In this part, we provide some numerical examples to illustrate the impact of the EVM under different modulation type.

As we mainly study the performance of HOM, the comparison is focus on high SNR region. With the simulation assumption which is shown in Table 1 and Table 2, following evaluations are carried out.

**Evaluation 1:** In this evaluation, we assume that EVM=0. In this ideal scenario, the spectrum efficiency of different MCStype are compared. As shown in Fig. 3, when SNR is higher than 30 dB, 256 QAM can achieve higher spectrum efficiency than 64 QAM. We also noticed that to achieve the highest spectrum efficiency with CQI 15, the SNR should higher than 35 dB.

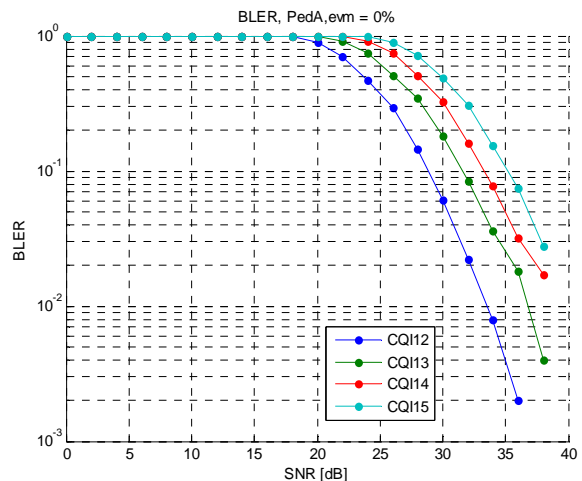
**Evaluation 2:** In this evaluation, the EVM is assumed as 0. The throughput with different evm is compared. With this ideal assumption, the BLER performance of 64 QAM and 256 QAM are

compared. Form Fig. 4, we can see that to keep the same BLER level, 256 QAM have to keep the SNR which is 2 or 3 dB higher than that of 64 QAM. We also noticed that to correctly demodulate 256 QAM signaling, the SNR should higher than 32 dB.



**Fig. 3.** Throughput of different MCS with EVM=0.

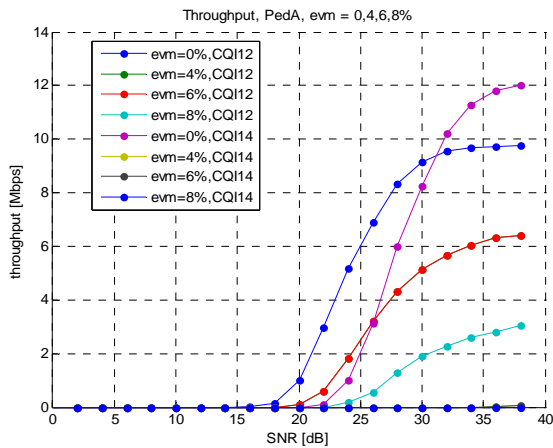
From the above two evaluations, we can come to know that although HOM can achieve higher spectrum efficiency, the needed SNR should higher than 30 dB.



**Fig. 4.** BLER of different MCS with EVM=0 %.

**Evaluation 3:** In this evaluation, we compared the spectrum performance with EVM of 0 %, 4 %, 6 % and 8 %. The evaluated CQI are CQI 12, and CQI 14, which are shown in Table 2.

As shown in Fig. 5, we can find that when EVM=4, 6, 8 %, the spectrum efficiency of CQI 14 is very low, which is much lower than CQI 12. This means that with EVM =4, 6, 8 %, the spectrum efficiency gain can hardly be achieved by HOM.



**Fig. 5.** Throughput comparisons of different MCS with EVM={0,4,6,8} %.

Evaluation 4: In this evaluation, we compared the BLER performance with EVM be 0 %, 4 %, 6 % and 8 %. The evaluated CQI are CQI 12, and CQI 14, which are shown in Table 2.

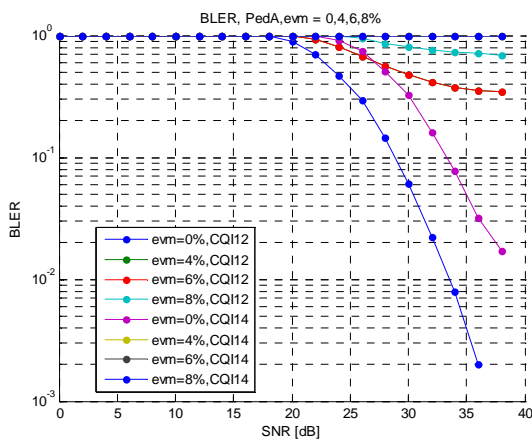
As shown in Fig. 6, we can observe:

1. When EVM=0 %, both CQI 12 and CQI 14 can work very well.
2. When EVM = 4, 6, 8 % the BLER performance are very poor.

From above evaluations, we can get following observations:

Observation 1: 256 QAM is very sensitive to EVM. Almost no performance gain can be seen from 256 QAM.

Observation 2: The MCSs using 256 QAM with high code rate can hardly ever be used. With EVM=4 %, the switching point is higher than 36 dB, and performance gain can be observed only with SNR is higher than 40 dB.



**Fig. 6.** BLER comparisons of different MCS with EVM = {0, 4, 6, 8} %.

## 6. Conclusion

In this paper, we analyzed performance of the HOM (higher order modulation) in small cell enhancement. Although HOM can be considered as one potential solution to improve system performance, the still have some problem to be studied. One important problem is to find out the impact of EVM.

Then, in this paper, we first studied the EVM modeling in LTE system, and then we analyzed the impact of EVM on HOM. We also provided the evaluation for the impact of EVM on different MCS (modulation coding style). Form the evaluation results, we come to know:

1. The HOM is very sensitive to the EVM;
2. To achieve the performance gain by HOM, very high SNR should be supported, which means it is only suitable for small cell.

It is also noticed that besides the Tx EVM, there still has other problems to be considered in HOM in small cell. For example, UE receiver impairments also affect the demodulation performance and therefore also need to be evaluated when considering 256 QAM. Relevant UE receiver impairments include the receiver non-linearity, IQ imbalance, frequency offset and phase error.

Therefore, besides the work in this paper, there still have many further interesting topics need to be studied further.

## References

- [1]. RP-122032, New study item proposal for small cell enhancements for E-UTRA and E-UTRAN – Physical-layer Aspects, 3GPP TSG-RAN Meeting #58, Barcelona, Spain, *Huawei, HiSilicon, CATR*, December 2012.
- [2]. M. Haardt, A. Klein, R. Koehn, S. Oestreich, M. Purat, V. Sommer, and T. Ulrich, The TD-CDMA based UTRA TDD mode, *IEEE Journal of Selected Areas in Communications*, Vol. 18, Issue 8, August 2000, pp. 1375-1385.
- [3]. Kan Zheng, Lin Huang, Wenbo Wang, Guiliang Yang, TD-CDMOFDM: Evolution of TD-SCDMA toward 4G, *IEEE Communication Magazine*, Vol. 43, Issue 1, January 2005, pp. 45-52.
- [4]. Inkwon Seo, Seyoung Won and Younglok Kim, Performance analysis of high order modulation schemes in the wireless communication system, in *Proceedings of the Conference on Advanced Communication Technology*, February 2007, pp. 203-211.
- [5]. R1-130856, Evaluation assumptions for small cell enhancements physical layer, *Huawei, HiSilicon, CATR, Barcelona, Spain*, August 2013.
- [6]. R1-131975, Link level evaluation results and discussion on 256QAM for small cells, *Samsung Electronics Research Institute*, October 2013.